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# CHAPTER 16

## TREEING

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### 1. INTRODUCTION

Treeing in extruded dielectric cable insulation is the term that has been given to a type of electrical deterioration that has the general appearance of a tree-like path through the wall of insulation. This formation is radial to the cable axis and hence is in line with the electrical field.

Trees that form in insulations such as polyethylene, crosslinked polyethylene, and ethylene propylene rubber cables are considered as two distinct types:

- ☐ Electrical trees
- ☐ Water trees (also known as electro-chemical trees)

They are differentiated by these and other parameters:

#### Electrical Trees

- Hollow tubes
- Water not required
- Rapid growth (hours, weeks)

#### Water Trees

- Discreet voids separated by insulation
- Moisture is required
- Slow growth (months, years)
- Must be stained to see them. This may be from chemicals in or around the cable or be stained as cable is examined.

## **2. BACKGROUND**

The phenomenon known as treeing in cables was first described by Raymer in 1912. He had been investigating electrical breakdown in the presence of discharges in paper insulated cables. The tree-like appearance of Lichtenberg figures was well known during the 1920s. These “trees” are totally different from what is seen in extruded dielectric cables because those older trees were carbon paths burned into the paper insulation that proceed concentrically around the insulating wall.

Treeing in extruded dielectric cables was described by Whitehead in 1932 in his work on electrical breakdown. The development of corona detection equipment in 1933 by Tykociner, Brown, and Paine made quantitative studies possible. Kreuger thoroughly described methods for detection and measurement of discharges in 1965.

The announcements by Vahlstrom and Lawson in 1971 and 1972 that direct buried HMWPE cables in URD systems contained trees made a significant impact on the cable industry. Previously reported results, especially by the Japanese, now became required reading.

## **3. FACTORS INFLUENCING ELECTRICAL TREES**

Partial discharges that decompose the organic material in insulations are generally considered the common factor in the formation of electrical trees. The intrinsic electrical strength of the commonly used material is many times higher than the electrical stresses that are encountered in actual service. How can these excellent materials fail at such low stresses? The presence of internal voids, contaminants and external stress points leads to electrical stress enhancements that are sufficiently high to originate water trees.

Impulses, surges, and dc stresses seem to create hollow channels through the insulation that we know as electrical trees. When seen in wafers, electrical trees are distinct and opaque. They usually do not have to be stained to see them, but staining is certainly a recommended practice. Electrical trees require high stress but not water, and they grow quickly.

## **4. FACTORS INFLUENCING WATER TREES**

Water (also called electro-chemical or chemical) trees grow at a slower rate than electrical trees that may take years to propagate and grow. Their appearance is sometimes obvious upon cutting wafers from aged cables, but their visibility stems from the staining of the interior of the tree wall by some form of chemical staining. Non-stained water trees disappear when the sample is dried. Staining

techniques are discussed later in this Chapter.

Water treeing is influenced by the following:

- Moisture
- Voids
- Contaminants
- Ionic impurities
- Temperature
- Temperature gradient
- Aging time
- Voltage stress
- pH

## **5. LABORATORY TESTING**

Treeing was considered to be a laboratory “trick” until the 1970s. Some of the earliest work was done by Simplex Wire & Cable. Kitchens, Pratt, Ware, Crowdes, and others reported on work done with one needle embedded in small slabs of polyethylene beginning in 1956. From this work, they developed the first commercial tree retardant HMWPE insulation. They reported in 1958 that moisture was an inhibitor to tree growth. What was not known at that time was that they were looking only at electrical trees. They confidently predicted in 1958 that “HMWPE may last more than 40 years in water at operating stress up to 45 volts per mil.” They were not aware of the existence of water trees as we now understand them nor did they repeat that statement made in that first paper that “...at the end of 40 years, half the lengths of cable will have failed.”

Other researchers in that same time period began using two embedded needles. They came up with similar conclusions. McMahon and Perkins reported in 1960 that “corona life of a specimen of HMWPE in air is a strong function of humidity. A relative humidity of 95 to 100% gives approximately 15 times longer life than dry air.” They were also only looking at electrical trees.

After the reported findings of Lawson and Vahlstrom and the Japanese reports in 1972 of “sulfide trees” in cables removed from the field, laboratory work moved towards wet testing of insulating materials such as the pie plate test of McMahon, and Perkins. By 1975, AEIC had developed an accelerated water treeing test on actual full sized cable samples placed in water filled pipes.

## **6. TECHNICAL DISCUSSION OF TREEING**

Treeing has been demonstrated as one of the most important factors involved in loss of life for medium voltage cables. Electrical trees are considered to be

associated with the final cable failure and do not exist for a long period of time. Water trees are the slower growing variety. They can extend from one electrode to the other without a service failure. Once they have formed, water trees seem to be converted to electrical trees for part or all of their length by dc, surges, and impulses. Conclusions in recent research work show that treed cables that are subjected to dc, surges, or impulses have shorter life in service after that application than cables not subjected to those stresses.

There are several possible explanations for this "conversion" of a water tree to an electrical tree, but the more commonly accepted explanation is that charges are trapped in the insulation wall. When these trapped charges are disturbed by heat or mechanical motion, they can literally bore a hole through the insulation wall. A likely scenario is that the trapped charges bore a tunnel from one void or contaminant to the next one. The insulation between these voids may be in a deteriorated condition, thus speeding up the damage from the trapped charges. This continues until the wall has been virtually destroyed and the cable can't hold even line voltage.

Inception of water trees is likely to be the result of voltage enhancements at voids, contaminants, or other imperfections in the cable. Another significant factor is the presence of ionic impurities have shown to be especially deleterious to cables. At one time it was thought that the source of these ions was from ground water or the like. It is now established that the frequent source of these impurities is the materials in the cable -- basically contaminants in the older semiconducting shield materials. Microscopically small "chunks" of sand make the insulation/shield interface another source of voltage enhancement. Growth or propagation of the water tree is apparently quite slow -- several years in a well made cable. Bow tie trees may stop propagating as they grow large enough to decrease the voltage stress at their extremities.

We know that voltage stress and temperature accelerate this propagation of water trees. Crosslinked and thermoplastic polyethylene are adversely effected by temperatures above about 75 °C -- as demonstrated by laboratory aging studies [16-10].

It is well established that moisture penetrates polymers. What has only been demonstrated in the past 20 years or so is that ac brings moisture toward the point of higher electrical stress. This is known as dielectrophoresis. Tanaka in 1974 presented this important concept that helps explain the growth of water trees.

As briefly mentioned previously, there is only a small distinction between water and electrochemical trees that results from a "natural" staining of the interior or the voids. Pre-1970 HMWPE insulation was formulated with a staining

antioxidant. These cable did not require any dying to see the trees. The change to non-staining antioxidant around 1970 resulted in water trees that could not be seen unless the wafers were put in a dye solution. In the transition period, it was thought that possibly the staining antioxidant was what had caused the trees! The dying procedure is given at the end of this section.

Trees also exist and are visible in EPR insulated cable but they can only be seen at the surface of the cut. A similar dying procedure is used for EPR but the staining time must be increased considerably. There are also proprietary methods for staining EPR cable samples. Tree counts in EPR are lower than for the non-opaque types because of not being able to see down into the material, but they also may be lower because they simply don't tree the same as XLPE cables.

Trees positively initiate at defects within the cable such as at discontinuities between the interfaces of the insulation and the two shields, and at voids and contaminants -- metal particles, threads, oxidized bits of insulation (ambers) and even at chunks of undispersed antioxidant.

Trees that have one of their points of origin at the insulation / shield interface are called "vented" trees. They always show up as the dangerous trees as compared to ones that stay completely within the wall of insulation -- the non-vented tree. The probable explanation here is that pressure can build up within the non-vented tree and this suppresses the partial discharge.

## **7. METHYLENE BLUE DYING PROCEDURE**

In a 500 ml beaker with watch glass cover, place:

- A. 250 ml distilled water
- B. 0.50 gm methylene blue
- C. 8 ml concentrated aqueous ammonia

Heat to boiling with continuous stirring. Use a fume hood or other adequate ventilation.

Place the specimens to be stained in the solution using a wire for installation and removal.

Remove specimens from hot solution from time to time to be certain that the staining is neither too light nor too dark.

When the specimens are adequately stained, remove from the hot solution, rinse in hot water, and wipe dry.

A thin film of oil on the surface of the sample makes observation with a microscope much less confused by scratches.

## **8. OBSERVATION IN SILICONE OIL**

An excellent method of observing several inches of insulation at one time is to place a one foot sample on the insulated cable (the semiconducting insulation shield must be removed!) in a glass beaker with silicone oil that has been heated to about 130 °C. At about this temperature, all of the crystallinity is gone and the insulation becomes quite clear. The surface of the conductor shield can be observed for smoothness. Voids or contaminants in the insulation wall can be readily seen. Note: "voids" can be created during the test by moisture in the insulation resulting from service conditions.

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